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TOOL ANALYSIS DEVICE AND METHOD

This invention relates to a device and method usable
for analysis of a tool during its use with a machine
5   tool, in particular but not exclusively for
determination of the position of a tool.

Toolsetting devices for determining the position of a
tool, which use a break beam system are known.
10 EP1050368 A1 describes in detail one system which has a
light transmitter and receiver. The transmitter
produces a beam of light and a receiver has circuitry
which produces a signal when obstruction of the beam is
detected. When a predetermined level of beam
15 obstruction e.g. 50% is reached then the signal
strength from the receiver is reduced such that a
trigger is produced. The trigger occurs when a tool is
present in the beam path.

20 A toothed cutting tool has to be rotated in order to
find its cutting diameter. Usually it will have at
least two teeth, one of which may be taller than the
other and so that tooth will circumscribe a larger
diameter than the other(s). When the tool is brought
25 into the beam path the tallest tooth may be at any
point and so the repeatability of the trigger will
vary. For example if a tool rotating at 1500rpm is
moving towards the beam at 6mm per minute then the feed
per revolution would be 6÷1500 which equals 0.004mm.
30 So, the repeatability of the trigger will be no better
than 4 microns because the largest tooth may break the
beam anywhere in that feed per revolution distance.
The feed per revolution of the measurement limits the
speed at which the tool can be driven into the beam and

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so slows the detection rate. Detection speed needs to
be maximised for quick operation of the machine tool,
whilst repeatability needs to be maximised also,
requiring slow feed rates.

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One known way to increase detection speed is to move
the tool quickly toward the tool setting device and
once detected to back off and then move in slowly to
determine the tool's position. This procedure, whilst
10   saving some time, is still relatively time consuming.

According to a first aspect the present invention
provides a tool analysis device for use on a machine
tool comprising a light emitter and a light receiver,
15   the light receiver in use receiving light from the
emitter and producing a signal indicative of the amount
of light being received, wherein the device further
comprises a converter for providing data having a
numerical representation of the signal produced by the
20   receiver and comprising also a processor for processing
that data and for producing an output when the data
conforms to a predetermined condition.

The processor may be a digital signal processor (DSP)
25   operative to process the data according to an
algorithm.

According to a second aspect the invention provides a
method for processing an analogue signal resulting from
30   light falling on a light receiver of a tool analysis
device for use on a machine tool, comprising the steps
of:
        converting the analogue signal into data having a
numerical form which represents the signal; and

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processing the data according to an algorithm.

Preferably the method provides a further step of:
    producing an output signal when instructed by the
5 algorithm when the data conforms to a predetermined
condition.

Preferably the method employs a DSP to process the data
and the algorithm is executed within the DSP.
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According to both aspects the predetermined condition
may be the data obtained when the light falling on the
light receiver is altered e.g. in such a way that the
tooth of a tool momentarily moves into and then out of
15 the light falling in the light receiver, or a series of
such events that conform to a predetermined pattern.
The pattern could be deviations in the amount of that
light such or a definable change in the magnitude of
those deviations, e.g. a decrease in magnitude from one
20 deviation to the next or a maximum followed by a
minimum followed by another maximum in that magnitude.

Embodiments of the invention will now be described in
detail with reference to the drawings, wherein:
25   Fig 1 shows a break beam type tool detector and
associated components;
        Fig 2 shows a schematic representation of elements
of the break beam tool detector shown in Fig 1;
        Fig 3 shows a flow diagram of an algorithm for use
30 with the invention;
        Figs 4,5,7 and 8 show simplified graphical
representations of signals produced during use of the
detector shown in Fig 1; and
        Figs 9-14 show graphs of actual output of a light

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receiver versus time obtained during use of a detector
of the type shown in Fig 1.

Fig 1 shows a break beam type tool detector 5. The
5   detector is suitable for use on a computer controlled
machine tool (usually called a CNC) having a machine
controller 56, a tool 50, a toolholder 52 and possibly
an automatic tool changer 54.

10   The tool detector 5 includes a laser light transmitter
12 (IR light is used in this instance), at transmitter
portion 10, a light receiver 34 at receiver portion 30
and a base 40 for mounting the transmitter and receiver
portions. A light beam 20 is created in use which can
15   be obstructed by the tool 50. Additional circuitry 32
is used also for processing the signal issued by the
light receiver 34. Whilst the circuitry is shown in
the receiver portion 30 some or all of it may be
located off the detector, e.g. as a PC interface card.
20   Fig 2 shows the circuit 32 in more detail. A
photodiode is used as the light detector 34. The
analogue signal from the photodiode is amplified at
amplifier 31 and is then sampled by an analogue to
digital converter (A-D) 33. The sample rate is
25   approximately 45KHz, but need not be that value. A
sample is called for by the digital signal processor
(DSP) and this processor runs a continuously looping
algorithm which calls for a sample at each loop. The
DSP is capable of parallel processing and so performs
30   its tasks very quickly. The algorithm used performs
the steps illustrated in Fig 3 and can be reset. In
practice background noise will be present and this will
be sampled by the DSP. As the beam is obstructed e.g.
by the tool, the signal from the receiver 34 will

change and thus will, in turn be sampled also. The
algorithm can cause an output when the data conforms to
a predetermined condition.

5   Prior to tool detection a calibration pin is detected
by the detector. A pin, in this instance similar in
size to the tool to be detected is brought into the
beam 20 by a program running in the CNC at a feed rate
of approximately 4mm/sec. The pin may be rotating or
10   non-rotating. The light receiver output will follow a
curve similar to that shown in Fig 4. That graph shows
the receiver output in volts V, versus time. A
straight line n represents the nominal upper voltage of
the receiver output with no beam obstruction. As the
15   pin is brought into the beam an oscillation in output V
is observed due to diffraction, then as less and less
light from the beam falls on the receiver the voltage
reduces along curve c and eventually drops to zero. In
particular a noticeable increase p in voltage is
20   observed as the beam begins to be obstructed. The
voltage during this calibration is processed by the DSP
and turned into digital information representing the
analogue output of the light receiver 34. The curve is
stored as a digital representation in the memory of the
25   DSP and is referred to below as the calibration curve
c. More than one curve can be stored.

When the tool 50 is brought into the beam at about the
same feed rate as the pin, whilst it is rotating, it
30   will have teeth which temporarily obscure a part of the
beam and these teeth cause voltage deviations s in the
signal from the receiver 34 as shown in Fig 5.

It has been found that the minima and maxima of the

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deviations shown in Fig 5 lie approximately on the
calibration curve c. The graph shown in Fig 5 is of an
idealised form, and in practice far more interference
or noise is observed than has been shown. However, the
5   voltage deviations shown will be present despite the
noise. For simplicity few deviations are shown,
however, in practice there may be many more than has
been shown because the tool will be rotating much
faster than is exemplified and consequently many more
10   interruptions to the beam will be observed. These
additional deviations will also have minima and maxima
which lie approximately on the calibration curve c.

The deviations present will differ in shape depending
15   on the tool type but the minima and maxima will still
lie on the calibration curve c.

Another set of deviations is shown in Fig 6. This
graph illustrates the voltage deviations obtained when
20   a two tooth cutting tool having one tooth taller than
the other is brought into the beam. In this instance
two sets of voltage deviations s and s' are formed, s'
lagging behind s. Each of these sets s and s' has
minima and maxima which lie on one of the respective
25   calibration curves c or c'.

Yet another set of deviations is shown in Fig 7. As
well as the deviations s this graph illustrates coolant
drips etc d which occur when the beam 20 is obscured by
30   material like machine coolant or swarf. These spurious
signals d do not conform to any pattern or curve and
occur randomly.

In each of the graphs of Figs 5,6 and 7 when background

noise and spurious signals d are ignored in favour of a recognisable set of voltage deviations s which are processed by the DSP.

5   Now, in this embodiment of the invention the voltage signals from the light receiver are conditioned using the circuitry shown schematically in Fig 2. Signal amplifier 31 amplifies the analogue signal and passes it to the A-D 33. The A-D in this example can operate
10   at a 96KHz sample rate but as illustrated in Fig 3 is driven to collect each sample by the downstream DSP 35. Once processed the sampled signals can be used e.g. to activate an output in the form of a trigger switch 37 e.g. to indicate that the edge of the tool has been
15   found.

In this example the predetermined condition is the data obtained when the beam is obstructed by the tool.

20   The processing of the digitised signal by the DSP can be carried out in a number of ways. The DSP is an ideal device for carrying out such processing because it is very fast and processes the data in real time, thus enabling short response times.
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One method of processing the sampled data involves deriving a polynomial e.g. cubic expression for the calibration curve c shown in Fig 4 and fitting, within tolerances, the minima and the maxima of the voltage
30   deviations s obtained in use of the device to that curve. If four minima and maxima values (more could be used) have been identified which fit to the curve within a predetermined time period then the DSP sends a trigger signal to switch 37 so that a 24v skip signal

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can be issued to the machine controller 56. The
machine controller can use this signal to determine the
position of the tool's edges and thereby its effective
cutting path.

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Alternatively an approximate straight line or
polynomial can be generated using the minima as points
on that line. No calibration curve(s) is (are)
required but rather, a threshold value can be

10 predetermined and when the straight line or polynomial
line is calculated to have crossed (or will cross when
extrapolated) that threshold then a trigger signal can
be generated. The calculations necessary for the line
generation again can be performed in the DSP. The

15 accuracy of the estimated threshold crossing point can
be improved if more than the minimum number of points
are used. A gradient method can be used to determine
minima or maxima and hence determine a threshold value.
The increase p can be used also to predict a threshold

20 crossing if required.

Drips or similar obstructions to the beam may give rise
to false readings during the use of the technique
mentioned immediately above. There are a number of

25 ways in which these false readings can be ignored. One
such way is to look for periodic voltage deviations
from the receiver 34 and then to open time periods
around the time when another deviation is expected.
Only in this period will digitising of the signal take

30 place. Thus, the chance of a drip occurring within
that period will be relatively small.

Another way to reject drips etc is to reject any
voltage deviation minima or maxima whose values lie

outside a band within which the next successive value
for a predetermined curve would be expected.

The above examples for processing of sampled data can
5   be used for non-rotating or rotating tool detection
including the detection of the lengths of rotating
drills etc which, when brought into the beam on axis
may appear to be non-rotating.

10 Another method of processing the sampled data from the
edge of a rotating tool is to look for voltage
deviations which have a distinctive character. A detail
of one such voltage deviation is shown in Fig 8. For
certain signals, the deviation of the voltage when a
15 cutting tool tooth obstructs the beam has a distinct
shape caused by optical effects. The shape occurs only
when a rotating part enters and leaves the beam. This
distinctive shape can be detected by operating an
algorithm in the DSP. This algorithm will look for the
20 relatively high amplitude maximum h followed by a
relatively high amplitude minimum s followed by another
relatively high amplitude maximum h. The minimum of
that deviation and the minimum of subsequent similar
deviations can be identified as tooth edge deviations
25 and can thus be used to form a curve which can be
fitted to a polynomial. No calibration curve(s) is
(are) required for this method.

The characteristic shape mentioned above may be a
30 min-max-min as well as the max-min-max described.

A method of rejecting drips when detecting rotating
tools is to ignore voltage deviations which do not have
the expected distinctive character i.e. either min-max-

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min or max-min-max e.g. as shown in Fig 8.

The techniques mentioned above for determining the
position of a tool rely on the calculation of the
5   minima and maxima of the voltage deviations s which
occur when a tooth obstructs the beam. There are a
number of well-known techniques for estimating the zero
slope part of a curve from points on either side of
minima or maxima which may be used.
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Fig 9 shows a graph of actual signals sampled from the
output of a tool detector of the type shown in Fig 1.
In this graph one square along the V axis represents 1
volt and one square along the time axis represents
15   approximately 25msec.

A calibration pin has been brought into the beam and
has caused the characteristic curve c which is shown in
Fig 4 in simplified form. The nominal voltage n is
20   5.5v and the receiver voltage drops to zero when fully
obstructed.

Fig 10 shows a graph of actual signals sampled from the
output of a tool detector. In this graph a rotating
25   tool (a 12mm slot drill) is brought into the detector
beam and its teeth have produced the signal as they
obstruct the beam. The graph squares represent 1 volt
and about 120msec. Superimposed on the graph is a the
curve c which approximates to the curve c in Fig 9.
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Various typical shapes of the data plots at points F11
to F14 along the curve are shown in more detail in Figs
11 to 14 respectively. In each of the graphs shown in
Figs 11-14 one square represents 0.5v and about 5msec.

In Fig 12 the obstruction signal is still in its oscillatory phase and has a min-max-min shape. In Fig 12 a trough develops in the max and thus a min,max,min,max,min shape develops. In Fig 13 that

5   middle trough becomes bigger. At Fig 14 the trough is larger than the other signals. The signal in Fig 14 is the max-min-max signal referred to above which has the distinctive shape that can be recognised and can be distinguished from other spurious signals.

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Tools which are brought into the beam along their axis of rotation e.g. drills brought in tip first also have this characteristic "c" shape.

15   Thus it can be seen that the voltage deviation that is detected by the algorithm in the DSP develops as the tool is progressed into the beam. As mentioned above, there are many ways in which the sampled data can be used to determine a trigger point.

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The max-min-max signal shown in Fig 8 changes progressively as the tool moves into the beam. The time t between the max peaks of the max-min-max increases as the tool progresses into the beam. The

25   time t is shown also in Fig 5 as t1,t2,t3,t4,t5 etc. This increase (or decrease if the tool is leaving the beam) can be determined by the DSP and used to determine where the tool is in relation to the beam. Thus a trigger threshold can be set when a certain time

30   t is reached for the recognisable max-min-max signal shown in Fig 8. If the rate of increase of t is determined as the tool is progressed then with a known velocity of tool relative to the beam it will be possible to determine other tool characteristics such

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as tool geometry. If the change in t is determined for
a given travel of the tool then, with constant tool
angular velocity, the diameter of the tool can be
determined.

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It has been found that the curve c shown in Figs 4-14
follows the distinctive shape shown, even if the tool
or obstruction in the beam is not rotating as it enters
the beam. Thus such a shape can be detected by the
10 algorithm in the DSP, e.g. by determining progressive
min values (s in Fig 8). It is not essential that a
calibration curve (c in Fig 4) is generated prior to
tool analysis because the curve will follow a
recognisable path of min values.

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Thus it can be seen that there are a number of ways in
which data derived from receiver 34 can conform to a
predetermined condition indicative of a tool present in
the beam 20 e.g.:
20   a number of repeated signals e.g. max,min,max
which have a characteristic profile;
        the shape of curve c may conform to a calibration
curve or may have an expected shape;
        the time t (Fig 8) may vary such that a prediction
25 of the position of the tool can be made; or
        successive peaks h (Fig 8) may be encountered.

A DSP has been utilised in the embodiment described,
however many alternatives exist. Processing of the
30 digitised signal could be carried out using e.g: a
Field-Programmable Gate Array, an application-specific
integrated circuit or a general-purpose microprocessor
e.g. a PIC or a PC based system.

The tool detector is shown as a break beam type, but could be a reflective type.

Any edge of a tool can be detected e.g. side or end.
5   Usually a calibration curve will be generated for each edge which is to be detected, but such a curve is not essential for edge detection.

The graphs show generally voltage output of a light
10   receiver but any other variable can be employed. The voltage etc may not drop fully to zero, particularly if a very small tool is to be detected and where only a portion of the beam is obstructed.

15   Detection can be made when the tool is coming out of the beam as well as going into the beam. In such circumstances the effects detailed above will be reversed. Tools or other items to be detected need not be rotating to be detected.
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As described above the minima or maxima of voltage deviations or deviations of variables can be fitted to a curve or simply used to plot a line. In either instance a trigger point equivalent to a voltage (etc)
25   threshold can be set.